

# Capturing and Processing Soil GHG Fluxes Using the LI-8100A



App. Note 138

## Introduction

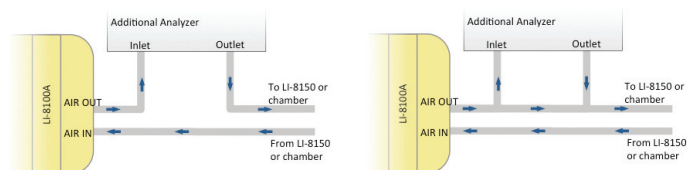
The LI-8100A Automated Soil CO<sub>2</sub> Flux System is designed to measure CO<sub>2</sub> efflux from soils using automated chambers and a closed-transient measurement approach. While CO<sub>2</sub> is an important gas in many contexts, it is not the only gas of interest for many research applications. By exploiting some simple ‘hooks’ in the system, a third party analyzer capable of measuring other trace gases can be interfaced with the LI-8100A System, and LI-COR’s data processing software (SoilFluxPro™) can be used to compute fluxes for these additional gases. In this application note we describe considerations for selecting an appropriate third party analyzer to interface with the system, how to integrate it into the system, and the procedure used to compute fluxes of additional gases in SoilFluxPro. A case study is also presented demonstrating methane flux measurements using an Ultra-Portable Greenhouse Gas Analyzer (Ultra-Portable GGA, model 915-0011), manufactured by Los Gatos Research, a member of the ABB group, integrated into the LI-8100A System (Figure 1).



**Figure 1.** A multiplexed LI-8100A System deployed with the Los Gatos Research Ultra-Portable Greenhouse Gas Analyzer (model 915-0011).

## Flow, Volume, and Pressure Considerations

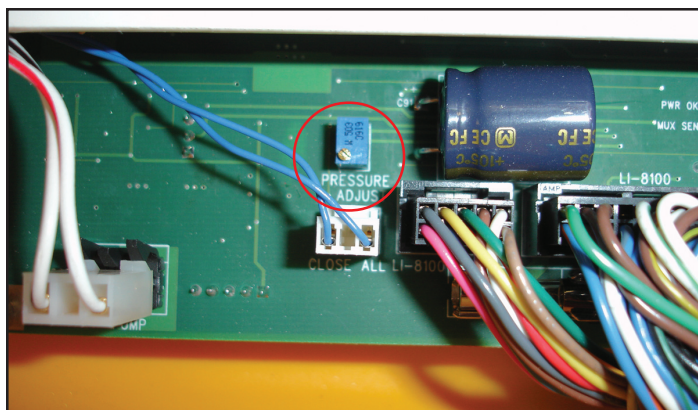
There are three flow loops inside a multiplexed LI-8100A System: the primary *sampling loop* between the multiplexer and chamber, the *subsampling loop* between the LI-8100A and the multiplexer, and the *pressure regulation loop* inside the multiplexer. Each of these loops operates at a different flow rate. The nominal flow rate through the subsampling loop is between 1.5 and 1.7 SLPM at near atmospheric pressure.



**Figure 2.** Plumbing schemes for connecting an additional analyzer to the LI-8100A System. Left hand panel: series configuration. Right hand panel: parallel configuration.

In a multiplexed configuration, the subsampling loop is where any additional analyzer should be placed, either in series with the air outlet from the LI-8100A or in parallel (Figure 2). Series placement is possible when the additional analyzer does not use its own internal pump and is capable of operating at the same flow rate and pressure as the LI-8100A. Parallel placement is required when the additional analyzer operates at a different pressure or flow rate different than the LI-8100A. In either configuration it is possible for the additional analyzer to cause a slight over-pressure on the LI-8100A optical bench. Care should be taken to avoid creating flow restrictions in the subsampling loop and where these cannot be avoided it may be necessary to adjust the bias on the pressure regulation loop. To adjust the pressure regulation loop:

1. With all plumbing modifications and the additional analyzer in place, note the LI-8100A optical bench pressure when all flow pumps are off.
2. Open the LI-8150 multiplexer and remove the splashguard that covers the fuses.
3. Locate the blue **Pressure Adjust** potentiometer (up and to the left of the fuses, as highlighted in Figure 3).
4. Turn on all flow pumps and look at the LI-8100A optical bench pressure. If it is different from the pressure noted in Step 1 use a small flat head screwdriver to adjust the **Pressure Adjust** potentiometer to minimize the pressure difference between when the pumps are on or off. Note that it may not be possible to bring the pressure differential to zero between when the flow pumps are on and off; within  $\pm 0.5$  kPa would be typical. If there is some offset, the calibration procedures outlined below should be followed to ensure that the LI-8100A performs as expected.



**Figure 3.** Pressure Adjust potentiometer.

When operating with a single chamber and standalone LI-8100A analyzer control unit, the third party analyzer should be placed on the AIR OUT line from the LI-8100A using one of the plumbing schemes described in Figure 2. The plumbing configuration follows the same guidelines when placing the additional analyzer in the subsampling loop of a multiplexed system. The flow rate between an LI-8100A and a single chamber, and the flow rate in the subsampling loop of a multiplexed system, are both nominally between 1.5 and 1.7 SLPM.

The volume of the additional analyzer will have at least two kinetic effects: 1) it brings additional air to the system, which dilutes trace gas entering the system from the soil surface and reduces the measured trace gas mole fraction rate of change ( $dC/dt$ ); and 2) it creates a time delay in the onset of a monotonic concentration increase or decrease. Accurate fluxes can still be measured if the added volume is sufficiently small.

The quantitative impact of the added volume on  $dC/dt$  can be evaluated by considering the equation used to calculate flux  $F$  ( $\text{mole } m^{-2}s^{-1}$ ). This equation is derived based on the assumption of a single fixed volume  $V$  ( $m^3$ ) with homogeneous air density  $\rho$ . For simplicity, in this discussion the effects of water corrections are neglected. This however, does not change the conclusions. Thus,

$$F = \frac{\rho V}{S} \frac{dC}{dt} \quad (1)$$

where  $F$  is the flux of trace gas ( $\text{mole } m^{-2}s^{-1}$ ), where  $\rho$  is air density ( $\text{mole } m^{-3}$ ),  $dC/dt$  is the time rate of change in mole fraction of the gas being measured ( $s^{-1}$ ), and  $S$  ( $m^2$ ) is the soil surface area over which the flux occurs. For a flux  $F$ , the trace gas mole fraction rate of change  $dC/dt$  is proportional to the total number of molecules in the system  $\rho V$ .

For a well-mixed system, when an additional volume  $V_{\text{added}}$  that contains a gas of density  $\rho_{\text{added}}$  is inserted into the system, equation 1 becomes

$$F = \frac{(\rho_{\text{system}}V_{\text{system}} + \rho_{\text{added}}V_{\text{added}})}{S} \frac{dC}{dt} \quad (2)$$

But  $\rho_{\text{system}} = P_{\text{system}}/RT_{\text{system}}$ , where  $R$  is the universal gas constant, and similarly for the added volume. Substituting these expressions and factoring gives,

$$F = \frac{\rho_{\text{system}}(V_{\text{system}} + V_{\text{added}} \frac{P_{\text{added}}}{P_{\text{system}}} \frac{T_{\text{system}}}{T_{\text{added}}})}{S} \frac{dC}{dt} \quad (3)$$

For data processing using SoilFluxPro, an effective volume  $V_{\text{effective}}$  for the addition can be defined for the added analyzer and entered into the software.

$$V_{\text{effective}} = V_{\text{added}} \frac{P_{\text{added}}}{P_{\text{system}}} \frac{T_{\text{system}}}{T_{\text{added}}} \quad (4)$$

Thus, the total volume used in equation (1) becomes simply  $V_{\text{system}} + V_{\text{effective}}$  and the density is  $\rho_{\text{system}}$ . The system density is computed using  $P_{\text{system}}$  (Pa) from the pressure measurement in the LI-8100A optical bench, and  $T_{\text{system}}$  (K) from the chamber air temperature. There are inherently small variations in  $V_{\text{effective}}$  due to changes in  $T_{\text{system}}$  and  $P_{\text{system}}$ , but these are generally small and subsequently neglected.

In many cases, the impact of an added volume on flux calculations will be modest as  $V_{\text{effective}}$  for many modern trace gas analyzers is small. For example, in the case study presented at the end of this application note, if the additional volume of the Ultra-Portable GGA were neglected, the error would be less than 1.5%.

By trapping air making its way around the measurement circuit, the volume of a third-party gas analyzer may also introduce an additional time delay and have other effects that can compromise the flux measurement. The magnitudes of these effects are related to the analyzer's volume  $V_{\text{added}}$  ( $\text{m}^3$ ), its operating pressure and temperature, and the flow rate through it. We can qualitatively assess the kinetic consequences of adding the volume by defining a time constant for the effective volume of the added analyzer and comparing it empirically to tested cases. We define a time constant  $\tau_{\text{added}}$  (s)

$$\tau_{\text{added}} = \frac{\rho_{\text{added}} V_{\text{added}}}{U_{\text{added}}} \quad (5)$$

where  $U_{\text{added}}$  is the molar flow rate ( $\text{moles s}^{-1}$ ) delivered to the analyzer,  $\rho$  is air density ( $\text{mole m}^{-3}$ ) in the analyzer evaluated at the analyzer's internal temperature and pressure, and  $V_{\text{added}}$  ( $\text{m}^3$ ) is its actual volume.

Time constants for different analyzers or model volumes inserted into the LI-8100A subsampling loop are shown in Table 1. The time constant for the gas analyzer in the LI-8100A is 0.5 s, while that for the Ultra-Portable GGA inserted in a parallel configuration is about 4.6 seconds; nevertheless, as shown below, both the LI-8100A and the integrated LI-8100A/Ultra-Portable GGA give accurate fluxes. We have also tested the impact of adding other volumes in series configurations, and found that accurate fluxes were observed when a volume was added having a time constant of about 7 seconds, but not 17 seconds (Table 1). Based on these results, we expect that third-party analyzers added in series or parallel with time constants less than 5 to 7 seconds may work well. We recommend fluxes made with any other configuration not shown here be validated. Validation can be straightforward if the third-party analyzer measures  $\text{CO}_2$  as well as other gases of interest.

**Table 1.** Time constants for different analyzers or volumes added to the LI-8100A subsampling loop. Temperatures and pressures pertain to conditions inside the added volumes or analyzers.

Analyzer or added volume	Configuration	Volume ( $\text{cm}^3$ )	P (kPa)	T ( $^{\circ}\text{K}$ )	Flow Rate (SLPM)	$\tau_{\text{added}}$ (s)	Flux OK?
LI-8100A	Series	14.5	98	323	1.7	0.5	Yes
Ultra-Portable GGA	Parallel	325	18.75	300	0.8	4.6	Yes
Test volume 1	Series	200	98	298	1.7	7.1	Yes
Test volume 2	Series	500	98	298	1.7	17.7	No

The configurations reported in Table 1 all affect  $dC/dt$  and introduce time delays. But for systems with appropriate time constants, accurate fluxes can be obtained by entering

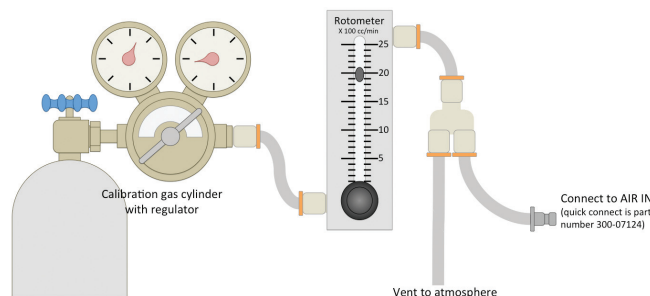
the appropriate volumes, adjusting the dead band to accommodate delays, and computing fluxes using SoilFluxPro.

## Calibration Considerations

The calibration procedures outlined in the LI-8100A user manual are adequate for normal operation of the instrument where optical bench pressure is not significantly altered from ambient. However, when plumbing additional volumes into the system, small pressure differences can cause offsets in the gas measurements when the standard calibration procedure is followed. These offsets tend to be small and may only be apparent when a  $\text{CO}_2$  measurement is available at two different points in the system.

When operating with a third party analyzer plumbed into the system an alternative calibration routine can be used:

1. With the system plumbed for operation with the third party analyzer, turn on the flow pumps and note the optical bench pressure.
2. Disconnect the hose from the air inlet (AIR IN) and connect the calibration rig as shown in Figure 4.
3. With the flow pumps on, adjust the flow rate through the rotometer such that bench pressure on the LI-8100A is as close as possible to what it was in Step 1. A slight pressure difference ( $\pm 0.5$  kPa) may be unavoidable and is okay. It is critical however, that flow through the rotometer exceeds the flow through the LI-8100A and that some small excess flow leaves the vent tube in the calibration rig. A flow rate of 2.0 to 2.5 LPM through the rotometer may be suitable to meet the demand of the LI-8100A pump and have a small flow out the vent.
4. When the gas concentration reading stabilizes, set the zero, span or span 2 using the LI-8100A interface software as described in the LI-8100A user manual.
5. Calibrating the third party analyzer following this same procedure may be advisable, as well. Check with its manufacturer for calibration details.



**Figure 4.** Calibration rig used to calibrate the LI-8100A at operating pressure.



Despite careful calibration, some offsets may be seen between CO<sub>2</sub> and water vapor as measured by the LI-8100A and some third party analyzer plumbed in line with it. These offsets can appear due to a number of reasons, and are not necessarily important in the context of the flux measurement. For water vapor, differences during a given flux measurement may be expected due to interactions with surfaces at different points in the system that lead to a differential time response for water vapor for the two analyzers. For this reason it is important to record both the concentration of the gas of interest and water vapor from the additional analyzer, or where available, record the dry mole fraction for the gas of interest.

For CO<sub>2</sub>, differences will occur due to an inherent time delay resulting from the additional analyzer being physically separated from the LI-8100A's analyzer; the magnitude of this delay is related to the volume, flow rate, operating pressure, and location of the additional analyzer. But differences may also occur due to drift of the LI-8100A over time or pressure induced calibration offsets as discussed previously. It should also be noted that the accuracy of the LI-8100A's analyzer is specified as 1.5% of reading.

In a closed system where fluxes are computed from a rate of change, measurement of absolute concentration may seem less important than ability of the analyzer to accurately measure a change in concentration. However, because the absorbance measured by the LI-8100A is a non-linear function of CO<sub>2</sub> (and water vapor) concentration over its calibration range, the absolute concentration and rate of change are interrelated, and offsets in the absolute concentration may have a small impact on the flux. In practice, this effect is small and arises because the slope of the calibration curve increases with increasing CO<sub>2</sub> concentration.

## Data Integration Methods

### 1. Using analog signals

If available on the third party analyzer, its analog outputs can be used to integrate data on the LI-8100A resulting in a single .81x file containing the time series for multiple gas species that can be processed in SoilFluxPro. If the system includes a multiplexer these output channels can be fed into one or more of the three auxiliary inputs available for the 8100-104 or 8100-104C chambers. In software, the auxiliary inputs from a single chamber can be mapped to all ports, allowing the third party analyzer to be connected at only a single location (Figure 5). For single chamber systems lacking a multiplexer, the outputs must be fed into

one or more of the four auxiliary inputs available through the 8100-663 Auxiliary Sensor Interface, regardless of the chamber used.

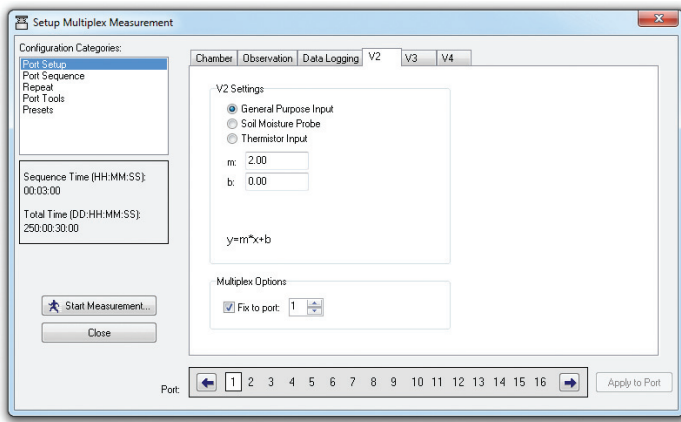
The auxiliary inputs available through either the chambers or the 8100-663 are measured in volts with 13 bit resolution over a 0 to 5V input range. The instrument software supports linear scaling (general purpose input), as well as a Steinhart-Hart conversion (Figure 5).

For integrating data in a multiplexed system an auxiliary input cable (part number 392-08577) is available that connects directly to the auxiliary inputs on the 8100-104 and 8100-104C chambers. This cable provides a weatherized connection at the chamber and bare leads to interface to the third party analyzer's analog outputs. One cable will be necessary for each channel in use, and due to the cable's length, the analyzer must be placed near the chamber it is connected to. A 2 m cable (392-07955) is also available that allows the additional analyzer to be attached directly to the LI-8150 in place of a chamber, allowing the LI-8150, LI-8100A and third-party analyzer to be collocated up to 15 m from the chambers. Only one of the 392-07955 cables is required to access all three of the auxiliary inputs. Pin outs for both cables are given in Table 2.

For connecting to the 8100-663 Auxiliary Sensor Interface a user supplied cable with a suitable connection to the third party analyzer on one end and bare leads on the other will be required. For details on how to connect to the auxiliary sensor interface see Chapter 2 of the LI-8100A user manual.

**Table 2.** Pin outs of cables that can be used to integrate analog signals into the LI-8100A System.

392-08577			392-07955	
Pin	Description	Wire color	Description	Wire color
1	Analog input (+)	Brown	Ground	White
2	4 mA limited, 5 VDC regulated reference output	Pink	Chamber temp. signal (+)	Brown
3	100 mA limited, 5 VDC supply	Blue	Analog Ground	Green
4	Not used	Grey	Auxiliary input V4+	Yellow
5	50 mA limited, unregulated output	Red	Chamber stop signal	Grey
6	30 mA limited, switched 5 VDC supply	Yellow	Auxiliary input V3+	Pink
7	Analog input (-)	Green	Chamber open and close signal	Blue
8	Ground	White	Auxiliary input V2+	Red
9	N/A	N/A	Switched 5V supply control	Orange
10	N/A	N/A	Voltage supply to chamber	Tan



**Figure 5.** Analog input settings. For a linear voltage input select **General Purpose Input** and use the  $m$  and  $b$  coefficients to scale the raw voltage to meaningful engineering units: recorded value =  $mV_{in} + b$ . In multiplexed configuration use **Fix to port** to route the analog inputs from one chamber to all the other chambers. This will ensure that the third party analyzer's data is recorded in the correct location in the data file.

## 2. Using an external data file

Where analog signals are not available, it is possible to integrate a separate data file from a third party analyzer in post processing using the import feature in SoilFluxPro. This allows fluxes to be computed for data collected remotely from the LI-8100A when analog outputs are not available from the additional analyzer. It is necessary that the data to be imported have time stamps that are reasonably synchronized with the LI-8100A; fixed offsets can be accounted for. The import routine will select or generate a data point from the import file for each record of the LI-8100A file. If there is not an exact match, it will pick the two closest values and interpolate. Thus, 1 Hz data is best, but is not required. The import routine supports native text file formats used by Los Gatos Research, Gasmeter, Picarro, and Aerodyne Research, and can also be configured to match a variety of others. For details on how to import external files see the SoilFluxPro user manual.

### Time keeping and clock synchronization between the LI-8100A and other system clocks

Importing data from a third party analyzer into the LI-8100A's .81x files through SoilFluxPro Software is done by matching time stamps between the two data sets. This requires that the two devices keep time relatively consistently between each other. In cases where an offset exists in the timestamps, a fixed offset can be applied and accounted for in SoilFluxPro during importation. This requires, however, that the offset be constant over the entire data set being processed. On short time scales it may be reasonable to assume drift is minimal and that the offset is approximately constant, with any additional small

deviations accounted for in the curve fitting process. Over longer time scales, the asynchronous nature of clock drift ensures that without some intervention the offset will not be a constant value.

There is no internal mechanism in the LI-8100A that allows the instrument clock to be synchronized to a standard, or for it to act as a standard for other connected devices. In its typical application, the LI-8100A system runs independently and relies on the user to manually set its clock through its interface software before collecting data.

For users wishing to automate clock synchronization there is hope however. The LI-8100A configuration grammar supports pushing a time and date stamp to the instrument through either its serial or Ethernet interfaces. This allows a computer or microcontroller connected to the instrument to serve as an external standard for the instrument's clock. In many cases the external standard can be the third-party analyzer (more details below).

### Configuration grammar

When a measurement is not active the following command can be used to set the time and date:

```
<SR><CFG><CLOCK><TIME>{HHMMSS}</TIME><DATE>{YYYYMMDD}</DATE></CLOCK></CFG></SR>
```

In situations where automated clock synchronization would be desirable, it is unlikely that there will be open windows where a measurement is not active (eg continuous sampling with a multiplexed system). Thus, before sending the command to update the clock, it will be necessary to send the following command to end the active measurement:

```
<SR><CMD><MEAS>STOP</MEAS></CMD></SR>
```

To restart the measurement, send the following:

```
<SR><CMD><MEAS>START</MEAS></CMD></SR>
```

This will restart the measurement using the settings from the active configuration. To avoid file naming errors that will prevent the measurement from restarting, select append mode when configuring and starting the initial measurement through the interface software.

All commands sent to the LI-8100A need to be followed with a line feed (ASCII 10) for the instrument to recognize them. The instrument sends an acknowledgment after receiving a valid command.

## 8100sync.exe

In cases where the third-party analyzer runs a Windows operating system (for example many Los Gatos Research and Picarro analyzers), clock synchronization can be done using a simple application, 8100sync.exe, and the Windows Task Scheduler.

8100sync.exe is a simple program that stops the active measurement, sets the LI-8100A clock to the system clock, and restarts the measurement. It can be configured to connect to the LI-8100A via a serial port or through a LAN connection. When launched the first time, the application prompts the user to select a serial port for communication. Entering 0 at the prompt will toggle the application to use an Ethernet connection and prompt the user to enter the instrument's IP address. This information is compressed into a simple configuration file that is stored in the same directory as 8100sync.exe for easy access. On subsequent runs, the application uses these settings to work out how to connect to the instrument with no user interaction.

The application can be made to run on a regular schedule using Windows Task Scheduler. Simply create a task that executes the application daily at a user specified time. We suggest choosing some time after midnight when an active sampling event is not expected (i.e., between chamber measurements) or when losing a single chamber measurement is of little concern. Midnight is when file splitting happens on the LI-8100A if daily files are chosen, and it would be best not to interrupt this with an attempt to set the clock. You can download the 8100sync.exe program at:

<http://www.licor.com/8100sync.exe>

## Curve Fitting and Computing Fluxes Using SoilFluxPro

To compute fluxes for additional variables included in the .81x file access the recompute dialog; this can be done for all records in a file using the **Recompute** icon at the top of the SoilFluxPro window, or for a single record by double clicking the record in the summary view and going to the **Recompute** tab in that record's observation view. Figure 6 shows the recompute window for a single record.

In the recompute dialog, click the + under **Flux Computations** to add an additional variable for which fluxes are to be computed. Under **Gas column label:** select the variable. In the example here methane mole fraction was logged as umol/mol through auxiliary input V2. Check the box for **Curve Fit** and select start and stop times for the curve fit.

These may need to be adjusted later. Under **Dilution correct with** select the channel where water vapor was recorded from the additional analyzer and use the scalar below it to scale the value to mol/mol. In the example, water vapor was logged on V4 as mmol/mol, so it needs to be multiplied by 0.001 to convert to mol/mol. If the third party analyzer reports dry mole fraction, then no additional dilution correction is needed. Under **Vext** input the effective volume calculated using the equation presented under *Flow, Volume and Pressure considerations*. In this case the additional analyzer has an actual volume of approximately 325 cm<sup>3</sup> and operates at 18.75 kPa and 300.12 °K. At a chamber pressure of 100 kPa and temperature of 298.5 °K the effective volume was 60.62 cm<sup>3</sup>. It should be noted that in the example presented here effective volume is treated as a constant. But in practice chamber temperature and pressure are typically not constant, leading to an effective volume that may be different for each measurement. However, when the effective volume is small relative to the total system volume the error associated with treating it as a constant may not be important; For the example presented here, changing the chamber temperature by 25 °C affects the total volume by less than 0.1% and for a 5 kPa change in chamber pressure, the effect is less than 0.04%.

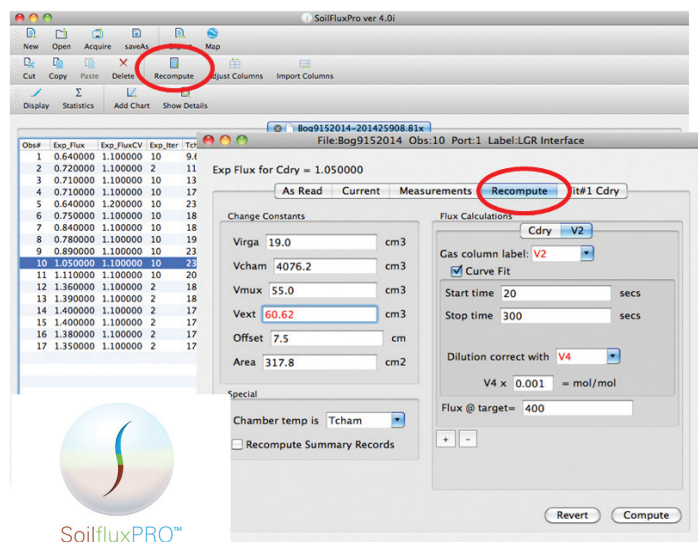


Figure 6. The Recompute dialog.

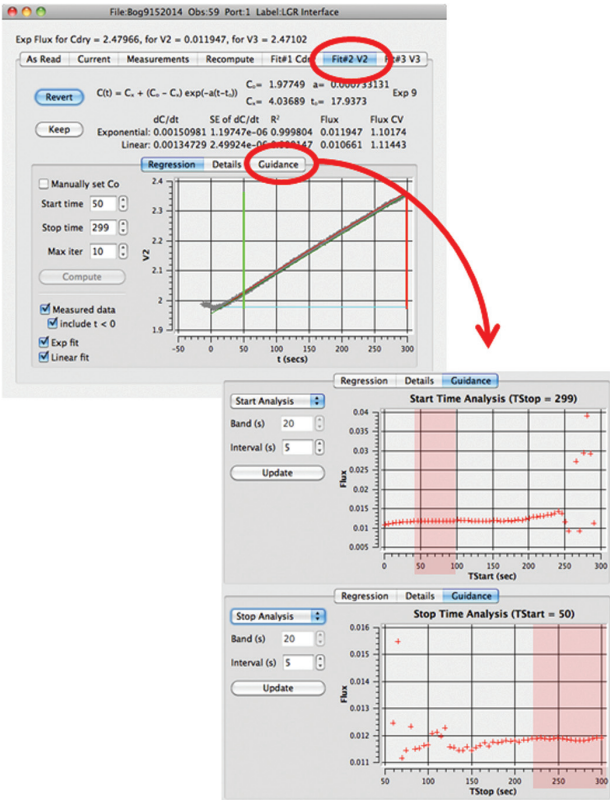
Open the observation view for a record and go to the tab for the additional flux computation. In the example shown here, the tab is labeled **Fit#2 V2** (Figure 7). Use the **Guidance** tab to determine appropriate start and stop times for the curve fitting. In the example dataset, a start time between 40 and 100 seconds and a stop time of greater than 220 seconds would work (shaded areas in Figure 7). For the start time look for the initial plateau and select a time in that window. For stop time, select a time after the



values level off. If the **Stop Time Analysis** curve does not level off or is very noisy, it is possible that the measurement length was too short. Once appropriate start and stop times have been determined it will be necessary to go back and recompute the data set if these times differ from the times used in the initial flux computation.

Note that for gas species with large fluxes and low resistance to diffusion in the soil, long measurement periods may lead to underestimations of the final flux due to buildup of the gas in the soil air space during the measurement. For gas species with low fluxes, such as methane, long measurement periods may be required to get enough data for a good curve fit. This means when measuring methane and carbon dioxide together, it will often be necessary to use different stop times for the two gases in the flux computation, with the stop time for carbon dioxide occurring much before that of methane.

Once satisfied with the curve fitting and summary values, the **Export** icon at the top of the main SoilFluxPro window can be used to export the summary values. For additional details on computing additional fluxes and exporting data see the SoilFluxPro manual accessed under **Help** in the software.



**Figure 7.** Viewing the curve fit for additional flux computations and using **Guidance** to select appropriate start and stop times. Windows with appropriate start and stop times are shaded in red.

## Example measurements using the Los Gatos Research Ultra-Portable Greenhouse Gas Analyzer



An Ultra-Portable GGA (model 915-0011) from Los Gatos Research, a member of the ABB group, was integrated into a multiplexed LI-8100A System (Figure 1) using a parallel plumbing configuration as shown in Figure 2. Data from the analyzer was brought

into the LI-8100A System using its analog outputs. Data collection was tested using both connection schemes described under *Data Integration Methods*. Wiring for the two cable sets tested is described in Table 3.

The Ultra-Portable GGA had an actual volume of approximately 325 cm<sup>3</sup> and operated at 18.75 kPa and 300.12 °K. Flow rate through the Ultra-Portable GGA was 0.8 SLPM. A chamber pressure of 100 kPa and temperature of 298.5 °K was used to compute the effective volume for the Ultra-Portable GGA and an effective volume of 60.62 cm<sup>3</sup> was used for all flux computations.

**Table 3.** Cable connections used to integrate data from the Ultra-Portable GGA. A pre-assembled version of the Turck to DB-9 cable described here is available from LI-COR (part number 9981-188).

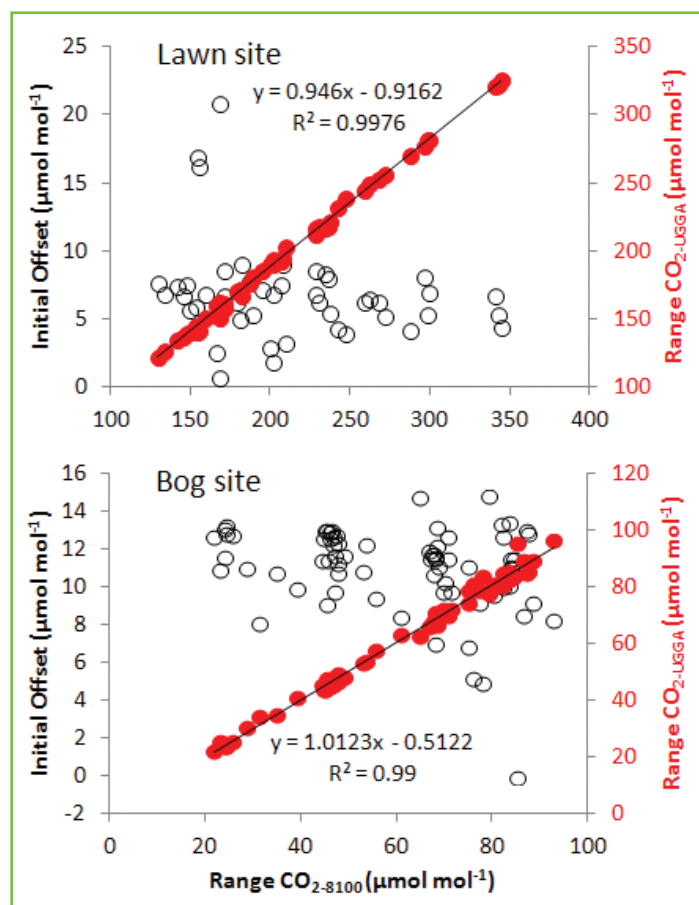
DB-9 connector to Ultra-Portable GGA	392-08577 wire color (three cables were used)	392-07955 wire color
CH <sub>4</sub> signal (pin 1)	Brown (cable 1)	Red
CO <sub>2</sub> signal (pin 2)	Brown (cable 2)	Pink
H <sub>2</sub> O signal (pin 3)	Brown (cable 3)	Yellow
CH <sub>4</sub> ground (pin 6)	Green (cable 1)	Green
CO <sub>2</sub> ground (pin 7)	Green (cable 2)	Green
H <sub>2</sub> O ground (pin 8)	Green (cable 3)	Green

Initial experiments were done in the lab to compare a known flux to the flux as determined from each analyzer's time series data. Known fluxes were generated by injecting pure CO<sub>2</sub> at a constant rate through a mass-flow controller into a sealed collar below an 8100-104 chamber. Data from these experiments are presented in Table 4 and show that for an artificial flux produced by mass-flow the LI-8100A and Ultra-Portable GGA give the same and expected result.

**Table 4.** Comparison of known mass-flow fluxes between the LI-8100A and Ultra-Portable GGA. Fluxes are given as  $\mu\text{mol m}^{-2} \text{s}^{-1}$  plus or minus one standard deviation.

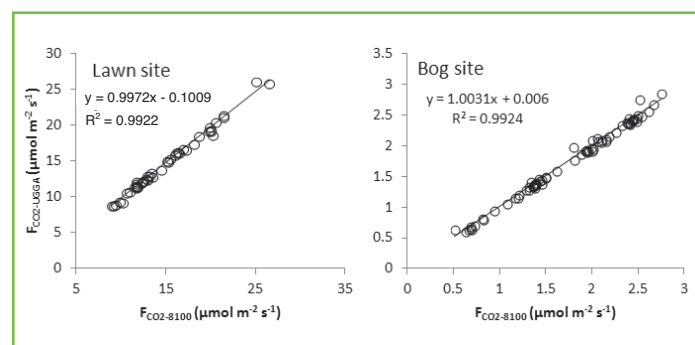
Injection Rate (SCCM)	Expected Flux	LI-8100A	Ultra-Portable GGA
0.1	$2.40 \pm 0.01$	$2.62 \pm 0.13$	$2.62 \pm 0.13$
0.2	$4.73 \pm 0.01$	$4.68 \pm 0.16$	$4.69 \pm 0.16$
0.4	$9.40 \pm 0.01$	$9.17 \pm 0.15$	$9.18 \pm 0.15$
0.8	$18.73 \pm 0.01$	$18.15 \pm 0.17$	$18.16 \pm 0.17$

The system was deployed on a mowed lawn and an artificial peat bog in Lincoln, NE to measure fluxes of carbon dioxide and methane. The two analyzers were cross calibrated prior to the laboratory experiments, but no subsequent calibration was performed prior to the field deployments. Figure 8 shows a comparison of the ranges and initial offsets in carbon dioxide concentration as reported by the two analyzers. While they showed a rather variable offset in concentration at the start of each measurement, the magnitude of change in concentration over each flux measurement was very similar for both analyzers at both sites.



**Figure 8.** Range and initial offset for the flux measurements made at the lawn and artificial bog sites. The initial offset is computed as the initial carbon dioxide concentration as reported by the Ultra-Portable GGA minus the initial carbon dioxide concentration as reported by the LI-8100A.

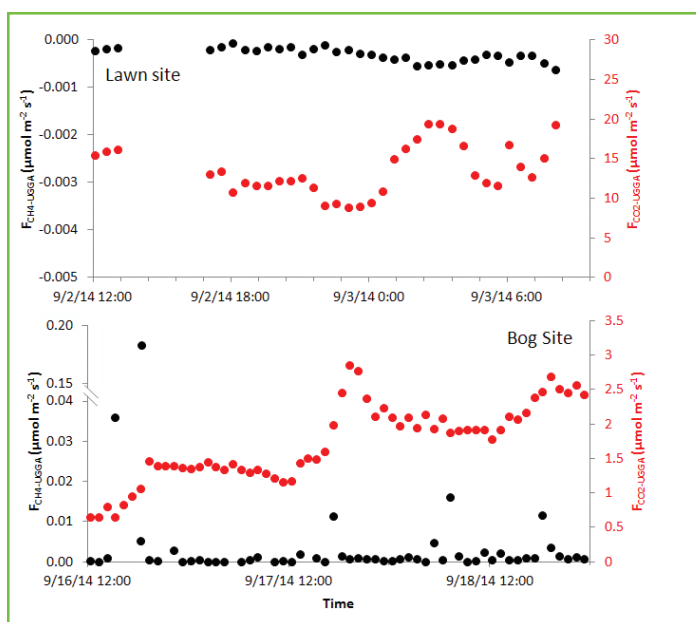
Comparisons were made between the diffusive fluxes of carbon dioxide computed from these data and are presented in Figure 9. Fluxes at the lawn site were quite large during the deployment due to warm weather (mean temperature of  $25.7^\circ\text{C}$ ) and abundant soil moisture, and quite low at the artificial bog, presumably due to cooler temperatures (mean temperature of  $19.4^\circ\text{C}$ ) and low gas conductance of the saturated peat. Once fit with appropriate start and stop times for the curve fits, the carbon dioxide fluxes from both analyzers at both sites showed little difference (approximate difference of 0.3%) despite the offsets observed in the absolute concentrations as reported by the two instruments.



**Figure 9.** Comparison of exponential fluxes for carbon dioxide from the lawn and bog sites for the Ultra-Portable GGA ( $F_{\text{CO}_2\text{-UGGA}}$ ) and the LI-8100A ( $F_{\text{CO}_2\text{-8100}}$ ). For the lawn site the curve fits were done for the Ultra-Portable GGA using a 40 second start time and 120 second stop time. For the Ultra-Portable GGA at the bog site a 30 second start time and a 120 second stop time were used. At both sites start times for the LI-8100A were 20 seconds and stop times were 120 seconds.

Methane fluxes at the two sites were small, but consistent with expected trends given soil conditions (Figure 10). At the lawn site a small negative flux was observed (mean of  $-3.3 \times 10^{-4} \mu\text{mol m}^{-2} \text{s}^{-1}$ ), presumably due to methane oxidation. At the artificial bog fluxes were nominally zero for most measurements, but did show positive fluxes (maximum of  $0.18 \mu\text{mol m}^{-2} \text{s}^{-1}$ ) in the late afternoon when the soil under the chamber was exposed to direct solar radiation.





**Figure 10.** Fluxes for methane and carbon dioxide at the lawn and bog sites as measured by the Ultra-Portable GGA. Curve fitting for carbon dioxide is the same as described in Figure 9. For methane at the lawn site the curve fitting is the same as for carbon dioxide. At the bog site a start time of 30 seconds and a stop time of 300 seconds was used for the methane flux.

## Useful Part Numbers

The table below contains a list of useful parts that can be used to connect the LGR Ultra-Portable GGA (or other third party analyzers) to the LI-8100A/LI-8150 and soil chamber(s). The 9981-188 and 9981-189 contain pre-assembled kits; note, however, that some additional parts may be required, depending on your method of connection.

Complete Kits	Description
9981-188 <sup>(1)</sup>	Pre-assembled Turck to DB-9 cable for connecting the Ultra-Portable GGA to the LI-8150 (includes 392-07955).
9981-189 <sup>(1, 2)</sup>	Pre-assembled hose assembly for plumbing the Ultra-Portable GGA in parallel to the LI-8100A subsampling loop.
Additional Parts	Description
8150-250 <sup>(1, 2)</sup>	Bev-a-line tubing (15m roll)
300-07385	1/4" Quick-connect 'T' fitting
300-03367	1/4" Quick-connect 'Y' fitting
300-03123	1/4" Quick-connect straight union
300-07124 <sup>(1, 2)</sup>	Male stainless steel quick-connect (connects to LI-8100A AIR IN)
300-07125 <sup>(1, 2)</sup>	Female stainless steel quick-connect (connects to LI-8100A AIR OUT)
294-03334	0-2.5 LPM flow meter (rotometer)
300-08118	1/8" NPT to 1/4" quick-connect right angle fitting (two used with rotometer)
392-08577 <sup>(1)</sup>	Auxiliary sensor input cable for 8100-104 or 8100-104C chambers
392-07955 <sup>(1)</sup>	Turck to bare leads cable, 2m long
314-03430 <sup>(1)</sup>	Male DB-9 connector with shielded housing (used to access Ultra-Portable GGA's analog outputs)

<sup>1</sup> For use with analog connections.

<sup>2</sup> For use with external analyzer integration.



**Figure 11.** LI-8100A Automated Soil Flux System, with (clockwise from top) LI-8150 Multiplexer, 8100-104C Clear Long-term Chamber, LI-8100A Analyzer Control Unit, 8100-103 20cm Survey Chamber, 8100-102 10cm Survey Chamber, and 8100-104 Long-term Chamber.

## NOTES

# LI-8100A System Specifications

## Analyzer Control Unit

**Power Requirements:** 10.5 VDC to 28 VDC; 3 A @ 12 V (36 W) maximum during warm-up; 1 A @ 12 V (12 W) average  
**Operating Temperature Range:** -20 °C to 45 °C  
**Relative Humidity Range:** 0% to 95% RH, Non-Condensing  
**Weatherproof Rating:** Tested to IEC IP55 standard  
**Dimensions:** 29 cm L x 38.1 cm W x 16.5 cm H (11.4" x 15" x 6.5")  
**Weight:** 5.3 kg (11.8 lbs) without battery; 6.7 kg (14.8 lbs) with battery  
**Battery Weight:** 1.4 kg (3.0 lbs)  
**Memory:** 18 MB flash memory for data collection (32 MB total)  
**Compact Flash Card:** Type I industrial grade, 1 GB with adapter sleeve included, will accept Type II with appropriate adapter sleeve  
**Wireless PC Card:** Fixed wireless networking Type II PC Card. Cisco Systems Aironet® 350 Series 11 Mbps DSSS for Wi-Fi (802.11b) networking  
**RS-232 Maximum Output Rate:** 1 Hz  
**RS-232 Baud Rate:** 57,600 bps  
**Hand-held Device Requirements:** Apple iOS 4.0 or greater  
**Pressure Sensor Range:** 15 kPa to 115 kPa  
**Pressure Sensor Accuracy:** 1.5% over 0 °C to 85 °C  
**Maximum Gas Flow Rate:** ~2.0 lpm

## Infrared Gas Analyzer

**Measurement Principle:** Non-Dispersive Infrared  
**Traceability:** Traceable to WMO standards for CO<sub>2</sub>. NIST traceable LI-610 Portable Dew Point Generator for H<sub>2</sub>O

### CO<sub>2</sub>

**Measurement Range:** 0 ppm to 20,000 ppm  
**Accuracy:** 1.5% of reading  
**Drift at 0 ppm:** <0.15 ppm/°C  
**Span Drift<sup>1</sup>:** <0.03%/°C  
**Total Drift at 370 ppm:** <0.4 ppm/°C  
**RMS Noise at 370 ppm with 1 sec signal averaging:** <1 ppm  
**Sensitivity to water vapor:** <0.1 ppm CO<sub>2</sub>/mmol/mol H<sub>2</sub>O

### H<sub>2</sub>O

**Measurement Range:** 0-60 mmol/mol  
**Accuracy:** 1.5% of reading  
**Drift at 0 mmol/mol:** <0.003 mmol/mol/°C  
**Span Drift<sup>1</sup>:** <0.03%/°C  
**Total Drift at 10 mmol/mol:** <0.009 mmol/mol/°C  
**RMS Noise at 10 mmol/mol with 1 sec signal averaging:** <0.01 mmol/mol  
**Sensitivity to CO<sub>2</sub>:** <0.0001 mmol/mol H<sub>2</sub>O/ppm CO<sub>2</sub>

<sup>1</sup>Residual error after zero correction

## LI-8150 Multiplexer

**Dimensions:** 40.6 cm L x 57.2 cm W x 21.1 cm H (16" x 22.5" x 8.3")  
**Weatherproof Rating:** Tested to IEC IP55 standard  
**Weight:** 9.4 kg (20.7 lbs), 8 ports; 11.2 kg (24.8 lbs) 16 ports  
**Operating Temperature Range:** -20 to 45 °C  
**Operating Humidity Range:** 0 to 95% RH, non-condensing  
**Maximum Spread:** 30.0 m (98.4 ft)  
**Flow Rate to Chambers:** ~3.0 lpm (non-adjustable)  
**Flow Rate Between LI-8100A and LI-8150:** ~2.0 lpm  
**Power Requirements:** 10.5 VDC to 14.5 VDC (120 VAC and 240 VAC with optional power supply)  
**Soil Temperature Thermistor (optional):** ±1.0 °C from -20 to 50 °C

## Long-Term Chamber - 8100-104

**Volume:** 4076.1 cm<sup>3</sup>  
**Soil Area:** 317.8 cm<sup>2</sup> (49.3 inches<sup>2</sup>)  
**Baseplate Dimensions:** 48.3 cm L x 38.1 cm W x 33.0 cm H (19" x 15" x 13")  
**Weatherproof Rating:** Tested to IEC IP55 standard  
**Air Temperature Thermistor:**  
**Operating Range:** -20 to 45 °C  
**Accuracy:** ±0.5 °C over 0 °C to 70 °C  
**Cable Length:** 15 m (49.2 ft)  
**Weight:** 5.9 kg (13 lbs)

## Clear Long-Term Chamber - 8100-104C

**Volume (Serial numbers 2024 and below):** 4076.1 cm<sup>3</sup>  
**Volume (Serial numbers 2025 and above):** 3876.1 cm<sup>3</sup>  
**Soil Area:** 317.8 cm<sup>2</sup> (49.3 inches<sup>2</sup>)  
**Baseplate Dimensions:** 48.3 cm L x 38.1 cm W x 33.0 cm H (19" x 15" x 13")  
**Weatherproof Rating:** Tested to IEC IP55 standard  
**Air Temperature Thermistor:**  
**Operating Range:** -20 to 45 °C  
**Accuracy:** ±0.5 °C over 0 °C to 70 °C  
**Cable Length:** 15 m (49.2 ft)  
**Weight:** 5.9 kg (13 lbs)



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